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SUMMARY

A study was conducted at the Dryden Flight Research Facility of NASA Ames Research Center (Ames-Dryden) to compare pilot effective time delay for the space shuttle rotational hand controller with that for conventional stick controllers. The space shuttle controller has three degrees of freedom and nonlinear gearing. The conventional stick has two degrees of freedom and linear gearing. Two spring constants were used, allowing the conventional stick to be evaluated in both a light and a heavy configuration. Pilot effective time delay was obtained separately for pitch and roll through first-order, closed-loop, compensatory tracking tasks. The tasks were implemented through the space shuttle cockpit simulator and a critical task tester device. A total of 900 data runs were made using four test pilots and one nonpilot (engineer) for two system delays in pitch and roll modes. Results showed that the heavier conventional control stick had the lowest pilot effective time delays. The light conventional control stick had pilot effective time delays similar to those of the shuttle controller. All configurations showed an increase in pilot effective time delay with an increase in total system delay.

INTRODUCTION

The space shuttle hand controller is different from a conventional aircraft stick in that it rotates in three degrees of freedom with short pivot lengths, while a conventional control stick has a more translational movement in two degrees of freedom with longer pivot lengths (figs. 1 and 2). Previous studies conducted by Systems Technology, Inc., under NASA contract (refs. 1 and 2) show that pilot effective time delay varies with stick stiffness and the order of the controlled element. Any time delay, whether it consists of pilot delay or vehicle system delay, is a critical parameter in aircraft handling qualities. For example, pilot-induced oscillations can occur during such critical tasks as landing and in-flight refueling when excessive time delays exist. The pilot effective time delay can be an important component of the total time delay when the pilot is in the loop. In some situations, a small change in vehicle system time delay results in large changes in handling qualities (ref. 3).

A study was made at NASA Ames-Dryden to compare pilot effective time delay, τ_e, for the space shuttle controller with that of more conventional stick controllers. Pilot effective time delay was obtained through a first-order, closed-loop, compensatory tracking task. This critical task uses an unstable controlled element where the instability is increased with time. Eventually, a critical point is reached where the unstable system cannot be controlled and the amount of instability at that point is an indication of the pilot effective time delay.

A critical task tester (CTT) that implements the critical task (fig. 3) was used to obtain τ_e values for the space shuttle rotational controller and the two conventional control stick configurations in both the pitch and roll axes at two system delays, with four test pilots and one nonpilot (engineer). The CTT was developed by Systems Technology, Inc., under previous NASA contracts.

NOMENCLATURE

CTT	critical task tester
e	base of natural system of logarithms (2.718)
j	imaginary number, $\sqrt{-1}$
K_c	controlled element constant
K_p	pilot describing function constant
s	Laplace operator
Y_c	controlled element
Y_p	pilot describing function
λ	inverse time constant, 1/sec
λ_{crit}	inverse time constant at critical time, 1/sec
τ_d	total system delay, msec
τ_e	pilot effective time delay, msec
$\Delta\tau_e$	increment in pilot effective time delay, msec
ω	frequency, rad/sec

DESCRIPTION OF EQUIPMENT

Three control stick configurations were installed in the space shuttle cockpit simulator located in the Ames-Dryden simulation laboratory. One configuration was the space shuttle rotational hand controller, which has three degrees of freedom and nonlinear gearing. A more conventional two-degree-of-freedom control stick equipped with two different spring constants constituted the other two configurations. This control stick had linear gearing and was center-mounted; however, the pivot point was between that of a conventional aircraft stick and a sidestick. The conventional stick was first tested with a stiff set of springs (heavy conventional stick) and later with a softer set of springs (light conventional stick). The designations "light," "heavy," and "conventional" are only relative, however, as the force gradients are lighter and pivot arms are shorter for this stick than that used in most aircraft center sticks. This is because the stick was a general-purpose engineering simulator stick and represented a compromise of a broad range of characteristics. The important characteristics of the three control stick configurations are presented in table 1 and figure 4.

The control stick signal, which is processed through the cockpit simulator, is operated with a 40-msec frame time and is then sent through the CTT. The total inherent time delay between pilot input and the CTT is 46 msec. The average sampling delay associated with the frame time accounts for 20 msec, and computation time accounts for 26 msec.

The CTT requires that the operator control a display indicator separately for pitch mode and roll mode. The operator is described by

$$Y_p = K_p \, e^{-\tau_e s}$$

where Y_p is the pilot describing function, K_p is the pilot describing function constant, e is the base of the natural system of logorithms (2.718), τ_e is the pilot effective time delay, and s is the Laplace operator. This first-order critical task uses an unstable controlled element

$$Y_c = K_c \, \lambda/(s - \lambda)$$

where Y_c is the controlled element, K_c is the controlled element constant, and λ is the inverse time constant. Figure 5 shows a block diagram and root locus of the total system without added system delay using a first-order Pade approximation for the $e^{-\tau_e s}$ term. As λ is increased as a function of time and error magnitude, the system becomes more unstable until control is lost. At that critical point, the value of λ approximates the reciprocal of the pilot effective time delay, τ_e equals $1/\lambda_{crit}$. Additional information may be found in references 1 and 4.

The pitch and roll indicators are displayed on an oscilloscope as a horizontal bar that moves vertically in pitch and pivots about the center in roll. The λ_{crit} values are read directly from a voltmeter. Figures 3 and 6 show the setup of the equipment.

TEST PROCEDURE

The test subjects for this study consisted of four test pilots and one nonpilot engineer. The subjects were oriented to the setup for the experiment through a series of trial runs. Gain settings in pitch and roll for each stick were determined from these trial runs by averaging the values preferred by each subject. The gain settings are as follows:

Stick control	Pitch gain	Roll gain
Space shuttle	1	3/4
Heavy conventional	3/4	1/3
Light conventional	3/4	1/3

A series of 15 runs for each configuration was conducted in the pitch and roll axes. The runs were repeated adding a system delay of 250 msec. Each of the five subjects made 180 runs, for a total of 900 test runs. The λ_{crit} values were recorded for each run, and the average for the series was computed for each subject (tables 2 and 3). The λ_{crit} values, which were read directly from the voltmeter, contain the 46-msec inherent time delay but not the added system delay of 250 msec when applied. (A time delay of 250 msec was chosen to simulate the total system delay nearer the value of that for the space shuttle.)

RESULTS AND DISCUSSION

The average λ_{crit} value from each series of 15 runs was converted to time delay; the 46-msec inherent time delay was subtracted from this value to obtain the pilot effective time delay (table 4). Figures 7 and 8 show the average τ_e value of each test subject as well as the combined average (solid bar) of all the subjects. Data for no added time delay (46 msec τ_d) are on the left, and data for 250-msec added time delay (296 msec τ_d) are on the right for each configuration.

Based on the combined average, the heavy conventional control stick had the lowest τ_e values for both pitch and roll, with and without added time delay (figs. 7 and 8). The shuttle rotational hand controller had the next lowest τ_e values in roll with no added time delay, while the light conventional stick had the next lowest τ_e values for pitch and roll with added time delay. The shuttle controller and light conventional stick had the same τ_e value (200 msec) for pitch with no added time delay. The highest τ_e values were for the shuttle controller in pitch and roll with added system time delay and for the light conventional stick in pitch and roll without added time delay. Scatter can be observed in the data in figures 7 and 8, but the trends with any given test subject seem to be consistent.

The changes in τ_e values between the shuttle controller and the control sticks, with and without added time delay, are evident in figures 7 and 8. Effective time delay for each subject increased when 250 msec was added to the system. On the average, the shuttle controller showed the most change – 70 msec in pitch and 60 msec in roll. For the heavy conventional stick, the average increase in pilot effective time delay was 50 msec in both pitch and roll. The average increase for the light conventional stick was 60 msec in pitch and 40 msec in roll.

These data show that the changes in pilot time delay caused by of differences in manipulator characteristics, are much less than the changes in pilot time delay caused by differences in total system time delay. This is consistent with results (unpublished) obtained from previous tests conducted by System Technology, Inc., under NASA contract NAS2-4405 (fig. 9). The data show very small changes in τ_e for a first-order controlled element as the gradient for a pencil controller changes from a free (unconstrained) to a rigid (force) stick. However, for a second-order controlled element, the τ_e is much larger and more sensitive to stick force gradient. Figure 10 presents the results of the Ames-Dryden experiment in a format similar to that in figure 9.

Figures 9 and 10 cannot be directly compared because of the differences in controller geometry, gradient, and controlled element time delay. However, some observations regarding general trends are valid. The increase in τ_e for the second-order controlled element (fig. 9) can be attributed to the additional mental processing which the pilot must perform to compensate for the integrator lag. The time delay in the controlled elements of figure 10 would also require pilot compensation (or lead); an increase in τ_e would therefore be expected. The change in pilot time delay for this experiment is not as large as that seen in figure 9. However, the variation in stick gradient for this experiment is not nearly as extreme as that used in figure 9. Perhaps even more significant is the difference in compensation required for the time delay compared to the integrator lag.

CONCLUSIONS

The space shuttle rotational hand controller and a more conventional control stick with two different spring constants were evaluated in both the pitch and roll axes using a first-order, closed-loop, compensatory tracking task implemented through a critical task tester device. Five test subjects performed a total of 900 data runs, that investigated total system delays of 46 msec and 296 msec. The data indicate that the heavy conventional controller had the lowest pilot effective time delay values in both control modes with and without added system time delay. The light conventional stick had effective pilot time delay characteristics that were similar to those of the space shuttle rotational controller.

Pilot effective time delay for all types of controllers tested increased with an increase in total system delay. The changes in pilot effective time delay, caused by increases in system time delay, were much more significant than changes caused by different controller characteristics.

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TABLE 1. – SHUTTLE CONTROLLER AND CONVENTIONAL STICK CHARACTERISTICS

Characteristic	Pitch-axis value	Roll-axis value
Shuttle rotational hand controller		
Breakout, cm-N (in-lb)	13.6 (1.2)	11.3 (1.0)
Travel, deg	±19.5	±19.5
Gradient, cm-N/deg (in-lb/deg)	13.6 (1.2)	37.3 (3.3)
Pivot point, cm (in)[a]	0.0 (0.0)	8.9 (3.5)
Heavy conventional stick		
Breakout, cm-N (in-lb)	5.6 (0.5)	2.3 (0.2)
At stop, N (lb)	48.9 (11.0)	48.0 (10.8)
Travel, cm (in)	5.1 (2.0)	±5.1 (2.0)
Gradient, cm-N/deg (in-lb/deg)	59.9 (5.3)	59.9 (5.3)
Pivot point, cm (in)[a]	17.8 (7.0)	17.8 (7.0)
Light conventional stick		
Breakout, cm-N (in-lb)	5.6 (0.5)	2.3 (0.2)
At stop, N (lb)	28.9 (6.5)	26.7 (6.0)
Travel, cm (in)	±5.1 (2.0)	±5.1 (2.0)
Gradient, cm-N/deg (in-lb/deg)	33.9 (3.0)	21.5 (1.9)
Pivot point, cm (in)[a]	17.8 (7.0)	17.8 (7.0)

[a]Measured from middle of palm point on control stick.

TABLE 2. – INVERSE TIME CONSTANT AT CRITICAL TIME, λ_{crit}, FOR PITCH AXIS

(a) No added delay

Subject	Test run															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Avg.
	λ_{crit}, rad/sec															
Shuttle rotational hand controller																
Test pilot 1	3.6	4.2	4.0	3.7	4.1	3.5	3.8	4.1	4.3	3.9	3.1	4.6	4.3	3.7	3.8	3.9
Test pilot 2	4.1	3.9	4.1	4.2	4.6	4.5	4.5	4.4	4.3	4.0	4.4	4.4	4.5	4.6	4.8	4.4
Test pilot 3	4.3	4.4	3.6	4.2	3.6	3.7	3.8	3.8	3.7	3.6	3.4	3.6	3.4	3.9	4.0	3.8
Test pilot 4	4.6	5.0	4.9	4.1	4.9	4.4	4.7	4.6	5.1	5.0	4.7	5.0	4.4	5.1	4.4	4.7
Nonpilot (engineer)	3.2	3.9	3.8	4.0	3.3	3.0	3.5	4.2	2.9	4.0	3.5	4.0	3.8	3.5	3.9	3.6
Heavy conventional stick																
Test pilot 1	4.4	4.2	4.5	4.4	4.7	4.8	5.1	4.3	4.6	4.8	4.4	4.3	4.8	5.0	5.1	4.6
Test pilot 2	5.6	4.5	4.8	4.8	4.6	4.5	5.0	4.3	4.5	4.4	4.7	5.2	4.8	4.7	4.8	4.8
Test pilot 3	3.1	3.7	3.8	3.2	4.1	3.0	4.0	4.0	4.2	4.5	4.3	3.8	3.1	3.6	4.0	3.8
Test pilot 4	5.2	5.0	4.2	5.0	5.0	5.0	4.8	5.1	4.7	4.8	5.5	4.3	4.5	4.4	5.6	4.9
Nonpilot (engineer)	4.9	4.7	4.7	5.0	4.4	4.9	4.2	4.0	4.5	3.7	4.4	4.1	4.3	4.4	4.7	4.5
Light conventional stick																
Test pilot 1	3.6	4.0	3.8	3.5	3.7	3.0	4.2	3.9	4.0	4.2	3.8	3.9	4.4	3.5	4.2	3.9
Test pilot 2	4.3	4.6	4.9	4.6	4.4	4.7	4.6	4.4	4.3	4.3	3.8	4.2	4.4	4.1	3.8	4.4
Test pilot 3	3.5	3.3	4.3	3.8	4.5	4.0	3.9	4.2	4.2	3.6	4.5	3.4	4.3	5.0	4.0	4.0
Test pilot 4	4.0	3.9	3.8	4.7	4.1	4.1	4.5	4.0	4.2	4.8	4.3	3.8	4.2	4.3	4.5	4.2
Nonpilot (engineer)	4.2	4.2	3.9	4.4	4.2	3.8	3.9	3.8	3.8	3.6	4.0	4.5	4.1	4.4	3.9	4.1

TABLE 2. – CONCLUDED

(b) 250-msec added delay

Subject	Test run 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Avg.
	λ_{crit}, rad/sec															
Shuttle rotational hand controller																
Test pilot 1	2.9	3.1	3.4	3.1	3.0	3.3	3.1	3.0	3.0	3.2	3.0	2.9	2.8	3.5	2.6	3.1
Test Pilot 2	3.0	3.1	3.3	2.9	2.9	2.7	2.7	2.6	2.7	3.1	3.6	3.4	3.1	2.8	2.9	3.0
Test Pilot 3	2.9	2.9	3.7	3.1	3.2	3.2	3.8	3.3	2.7	3.0	3.3	3.1	3.7	3.3	3.4	3.2
Test Pilot 4	3.2	2.9	2.8	3.1	3.5	3.4	3.1	3.3	3.2	3.2	3.1	3.6	3.4	3.5	3.3	3.2
Nonpilot (engineer)	3.3	3.1	3.1	3.2	3.1	3.3	2.9	3.3	2.8	2.9	3.0	2.8	3.2	3.1	2.9	3.1
Heavy conventional stick																
Test pilot 1	3.8	3.5	3.4	3.2	3.6	3.8	3.3	3.3	2.5	3.4	3.8	3.2	3.4	3.9	3.2	3.4
Test pilot 2	3.7	3.5	3.6	3.4	4.0	3.8	3.4	3.0	3.7	3.7	3.0	3.9	3.9	3.5	3.3	3.6
Test pilot 3	3.3	4.1	3.6	3.4	3.7	4.3	3.1	3.5	3.5	3.4	3.6	3.8	3.6	3.7	3.0	3.6
Test pilot 4	4.1	3.6	3.5	3.6	3.3	3.7	3.7	3.2	3.8	3.3	3.3	4.0	3.9	3.4	3.0	3.6
Nonpilot (engineer)	4.2	3.4	3.7	3.8	3.7	4.1	3.6	3.8	3.8	3.8	3.8	3.6	3.8	3.2	3.9	3.8
Light conventional stick																
Test pilot 1	3.8	3.5	3.7	3.8	3.7	3.3	3.9	3.4	3.7	3.6	3.8	4.1	3.5	3.1	3.9	3.7
Test pilot 2	3.4	3.4	3.7	3.4	3.3	3.1	3.0	3.4	3.2	3.3	3.0	2.8	3.2	4.2	2.9	3.3
Test pilot 3	3.3	3.8	3.1	3.8	3.2	3.4	3.3	3.3	3.2	2.7	3.1	2.6	3.0	3.5	3.1	3.2
Test pilot 4	2.9	2.9	2.5	2.8	3.0	3.1	3.1	2.5	3.0	2.9	3.0	2.9	3.4	2.9	3.2	2.9
Nonpilot (engineer)	3.5	3.1	2.8	2.8	3.4	2.9	2.8	3.1	3.1	3.5	3.3	2.9	2.9	2.7	3.9	3.1

TABLE 3. — INVERSE TIME CONSTANT AT CRITICAL TIME, λ_{crit}, FOR ROLL AXIS

(a) No added delay

Subject	Test run															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Avg.
	λ_{crit}, rad/sec															
Shuttle rotational hand controller																
Test pilot 1	3.8	2.9	3.6	3.5	3.3	3.6	4.4	3.3	3.9	3.5	3.3	3.2	3.4	3.4	4.2	3.6
Test pilot 2	4.0	4.0	4.0	4.4	4.1	4.3	3.9	4.6	4.1	4.0	4.1	4.8	4.7	4.4	4.8	4.3
Test pilot 3	4.7	3.9	3.8	3.9	4.2	4.1	4.2	3.8	4.6	4.2	4.8	4.4	3.8	4.0	3.5	4.1
Test pilot 4	4.4	4.6	4.6	4.8	4.2	4.6	4.7	4.4	4.6	5.3	4.9	4.9	5.2	4.4	4.8	4.7
Nonpilot (engineer)	3.9	3.6	3.6	3.9	3.8	3.9	4.4	3.8	4.1	4.0	3.9	3.9	3.5	3.6	3.6	3.8
Heavy conventional stick																
Test pilot 1	4.3	3.6	4.2	4.0	3.9	4.2	4.4	3.8	3.9	4.0	3.6	4.2	4.2	4.1	4.8	4.1
Test pilot 2	4.6	5.1	4.9	4.4	4.6	4.5	4.7	4.5	5.0	4.5	5.0	4.7	4.9	5.4	4.7	4.8
Test pilot 3	4.0	3.9	4.4	4.3	4.3	4.1	4.0	3.8	5.2	4.4	4.1	4.3	4.0	4.4	3.3	4.2
Test pilot 4	5.0	5.2	5.2	6.1	4.7	6.0	5.3	5.7	4.9	5.4	4.9	6.2	5.2	5.6	4.5	5.3
Nonpilot (engineer)	3.1	3.9	4.3	3.6	3.9	4.2	3.8	3.5	3.6	4.6	3.9	4.8	5.0	4.4	4.5	4.1
Light conventional stick																
Test pilot 1	4.1	3.6	3.6	3.2	3.4	3.7	3.2	3.2	4.0	3.8	4.0	3.8	3.9	3.4	3.3	3.6
Test pilot 2	4.4	4.2	3.6	4.5	4.8	4.8	4.8	4.7	4.7	4.6	4.5	4.8	4.6	4.4	5.2	4.6
Test pilot 3	3.8	4.1	3.6	4.2	3.6	4.3	3.4	3.5	3.7	3.6	3.7	4.1	4.4	3.1	3.2	3.8
Test pilot 4	4.5	4.6	4.8	4.4	4.9	4.3	4.0	4.7	4.4	4.3	5.0	5.4	4.7	4.7	4.5	4.6
Nonpilot (engineer)	3.6	4.1	3.7	3.8	4.1	4.5	3.9	4.2	4.5	3.9	4.1	4.1	4.0	4.3	3.9	4.1

TABLE 3. — CONCLUDED

(b) 250-msec added delay

Subject	Test run 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Avg.
	λ_{crit}, rad/sec															
Shuttle rotational hand controller																
Test pilot 1	2.9	2.7	2.7	2.7	2.4	2.8	3.2	3.4	2.5	2.7	2.8	3.2	2.9	2.9	3.1	2.9
Test Pilot 2	3.8	3.3	3.1	3.2	3.3	3.8	3.8	3.4	3.7	3.1	3.2	3.3	3.3	3.3	3.4	3.4
Test Pilot 3	3.3	3.3	3.2	3.2	3.6	3.2	3.0	3.1	3.4	2.7	3.3	3.8	3.8	3.3	3.4	3.3
Test Pilot 4	3.7	3.9	3.4	4.0	3.2	4.2	3.8	4.2	3.4	3.7	4.1	3.5	3.8	3.9	3.4	3.8
Nonpilot (engineer)	3.2	3.1	3.4	3.1	3.3	3.4	3.6	3.0	3.2	3.0	3.4	3.5	3.4	3.2	3.4	3.3
Heavy conventional stick																
Test pilot 1	3.3	3.6	2.9	3.1	3.3	3.7	3.3	3.1	3.2	4.0	3.0	3.2	3.4	3.0	2.9	3.3
Test pilot 2	4.2	3.8	3.4	3.9	4.0	4.1	3.1	3.4	4.0	4.1	4.2	4.0	4.3	4.0	4.4	3.9
Test pilot 3	3.2	3.4	3.8	3.8	3.1	3.2	3.9	3.3	3.6	2.9	3.4	3.0	3.2	3.5	3.6	3.4
Test pilot 4	3.6	4.1	4.1	3.8	4.0	3.8	3.6	4.1	3.8	4.0	4.5	4.2	4.5	4.6	4.2	4.1
Nonpilot (engineer)	3.6	3.5	3.5	3.8	3.7	3.9	3.7	3.3	4.2	3.7	3.2	4.0	3.3	3.3	3.6	3.6
Light conventional stick																
Test pilot 1	3.8	3.5	3.2	3.3	3.5	3.3	3.8	3.2	3.5	3.3	3.4	3.7	3.4	3.3	3.5	3.5
Test pilot 2	3.6	3.9	3.6	3.9	4.2	3.6	4.2	3.8	4.1	4.0	3.9	4.1	3.9	3.6	3.7	3.9
Test pilot 3	3.9	3.2	3.5	3.4	3.7	3.4	3.0	2.8	4.0	3.7	3.5	3.5	3.9	4.2	3.4	3.5
Test pilot 4	3.2	3.3	3.5	3.4	3.3	3.4	3.2	2.9	3.1	3.3	3.5	3.4	3.6	3.7	3.4	3.4
Nonpilot (engineer)	3.0	3.4	3.4	3.4	3.5	3.5	3.5	3.5	3.7	3.4	3.3	3.3	3.4	3.1	3.3	3.4

TABLE 4. — AVERAGE PILOT EFFECTIVE DELAY, τ_e, VALUES[a]

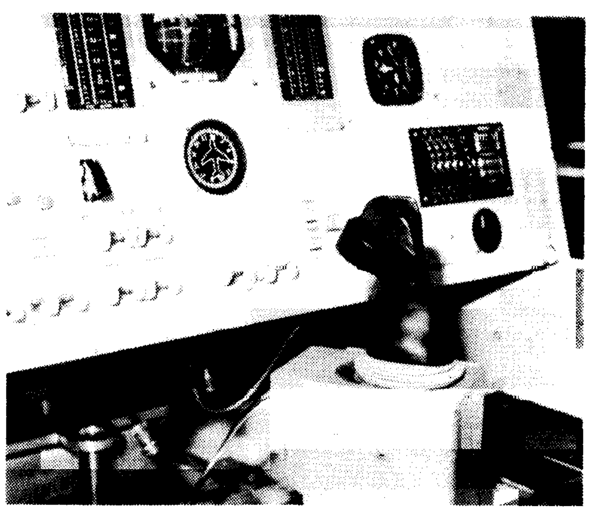
Subject	Pitch axis		Roll axis	
	No added delay	250-msec added delay	No added delay	250-msec added delay
	Average τ_e, msec		Average τ_e, msec	
Shuttle rotational hand controller				
Test pilot 1	210	280	230	300
Test Pilot 2	180	280	180	240
Test Pilot 3	210	260	190	250
Test Pilot 4	160	260	160	220
Nonpilot (engineer)	230	280	210	250
Heavy conventional stick				
Test pilot 1	170	240	200	260
Test pilot 2	160	230	160	200
Test pilot 3	220	230	190	240
Test pilot 4	160	230	140	200
Nonpilot (engineer)	170	220	200	230
Light conventional stick				
Test pilot 1	210	220	230	240
Test pilot 2	180	250	170	210
Test pilot 3	200	260	220	230
Test pilot 4	190	290	170	250
Nonpilot (engineer)	200	270	200	250

[a]All values have inherent delay of 46 msec subtracted from them.

TABLE 5. — DIFFERENCES IN AVERAGE PILOT EFFECTIVE TIME DELAYS, WITH AND WITHOUT ADDED SYSTEM DELAY

Subject	Pitch axis	Roll axis
Shuttle rotational hand controller		
Test pilot 1	70	70
Test pilot 2	100	60
Test pilot 3	50	60
Test pilot 4	100	60
Nonpilot (engineer)	50	40
Average[a]	70	60
Heavy conventional stick		
Test pilot 1	70	60
Test pilot 2	70	60
Test pilot 3	10	50
Test pilot 4	70	60
Nonpilot (engineer)	50	30
Average[a]	50	50
Light conventional stick		
Test pilot 1	10	10
Test pilot 2	70	40
Test pilot 3	60	10
Test pilot 4	100	80
Nonpilot (engineer)	70	50
Average[a]	60	40

[a]Least significant digit was rounded off.



ECN 24922A

Figure 1. Space shuttle rotational hand controller.

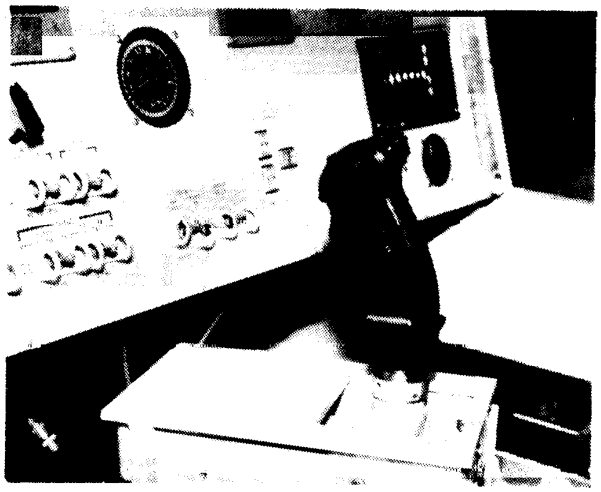


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Figure 2. Conventional aircraft controller.

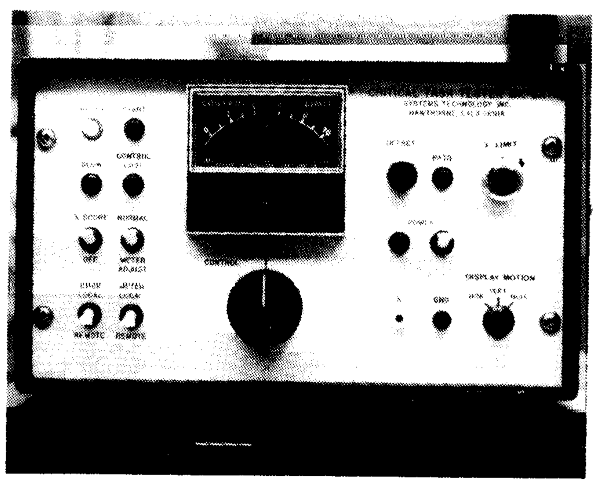

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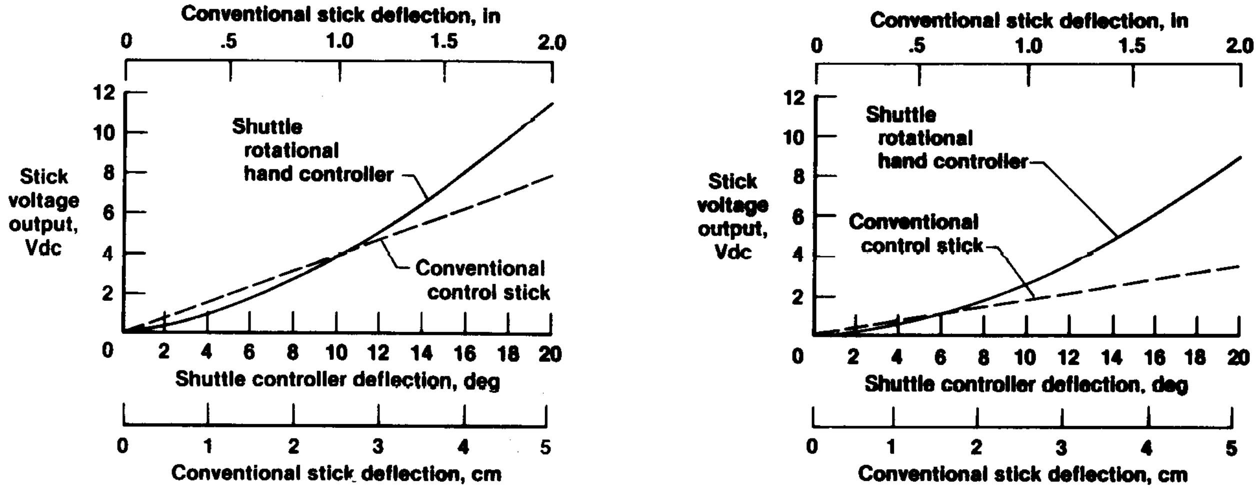
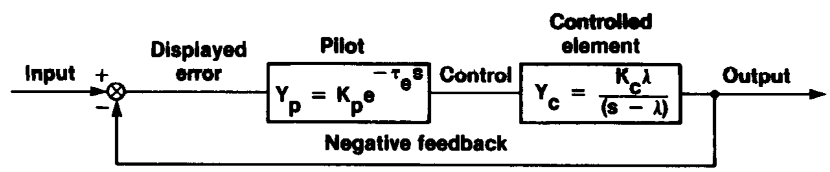
Figure 3. Critical task tester.



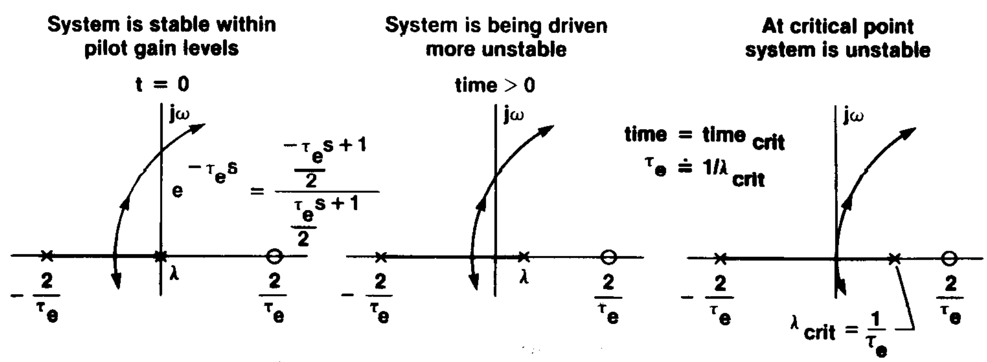
(a) For roll axis.

(b) For pitch axis.

Figure 4. Stick shaping for shuttle and conventional aircraft controllers.



(a) Block diagram.



(b) Root locus.

Figure 5. Total system without added system delay.

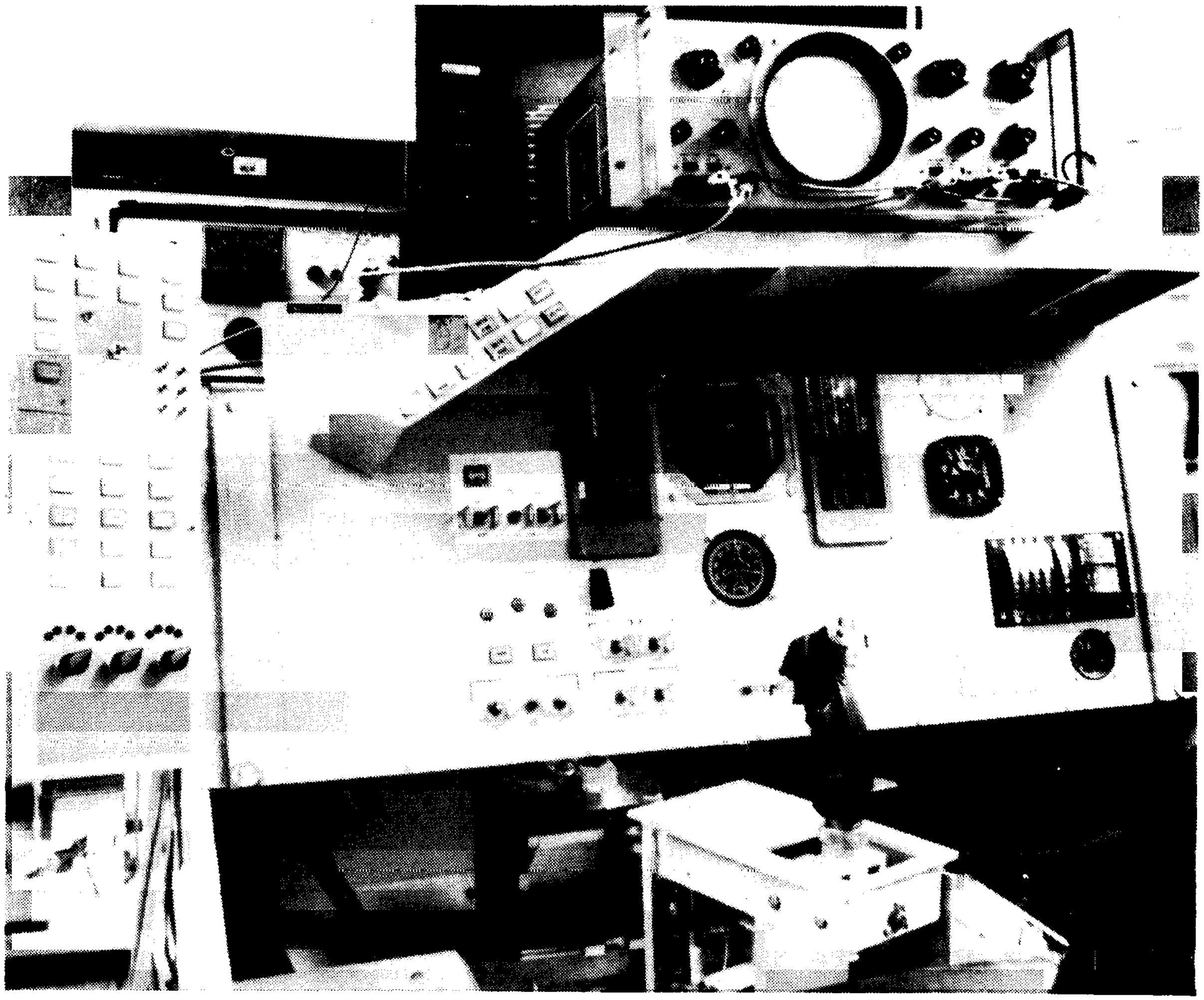


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Figure 6. Experimental equipment setup in space shuttle simulator cockpit.

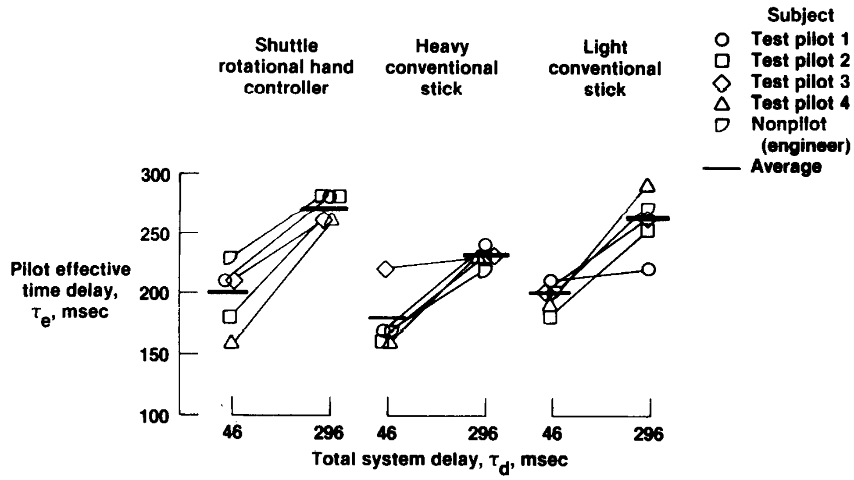

Figure 7. Summary of pilot effective time delay results for pitch control. (The 46-msec plot points are for inherent delay; the 296-msec plot points are for inherent plus added delay.)

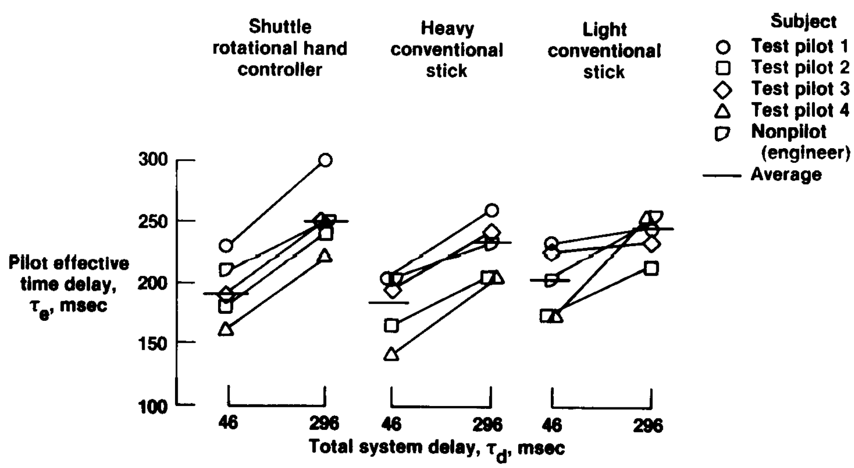

Figure 8. Summary of pilot effective time delay results for roll control. (The 46-msec plot points are for inherent delay; the 296-msec plot points are for inherent plus added delay.)

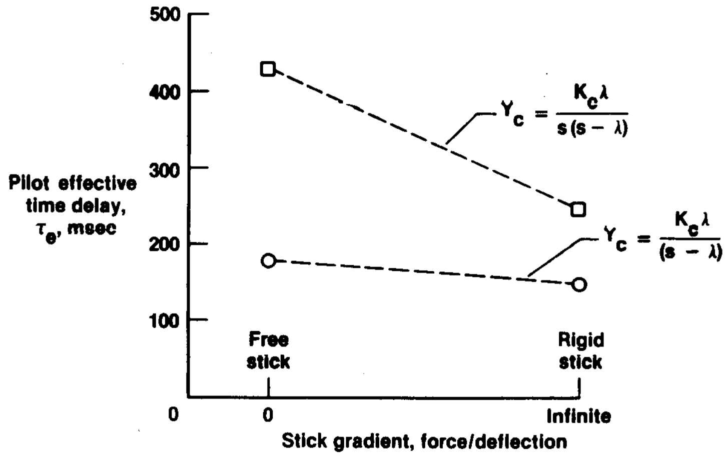

Figure 9. Pilot effective time delays for pencil control stick.

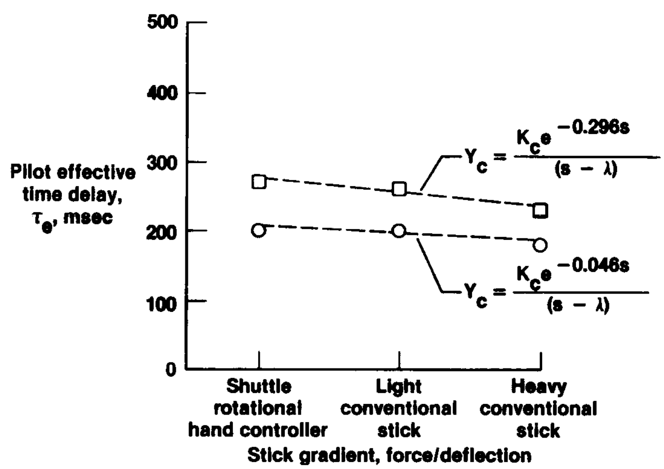

Figure 10. Pilot effective time delays for space shuttle and conventional aircraft controllers.

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16. Abstract

A study was conducted at the Dryden Flight Research Facility of NASA Ames Research Center (Ames-Dryden) to compare pilot effective time delay for the space shuttle rotational hand controller with that for conventional stick controllers. The space shuttle controller has three degrees of freedom and nonlinear gearing. The conventional stick has two degrees of freedom and linear gearing. Two spring constants were used, allowing the conventional stick to be evaluated in both a light and a heavy configuration. Pilot effective time delay was obtained separately for pitch and roll through first-order, closed-loop, compensatory tracking tasks. The tasks were implemented through the space shuttle cockpit simulator and a critical task tester device. A total of 900 data runs were made using four test pilots and one nonpilot (engineer) for two system delays in pitch and roll modes. Results showed that the heavier conventional control stick had the lowest pilot effective time delays. The light conventional control stick had pilot effective time delays similar to those of the shuttle controller. All configurations showed an increase in pilot effective time delay with an increase in total system delay.

17. Key Words (Suggested by Author(s))
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